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SUBHARMONIC TRIPLE BUNCHER FOR A HIGH-EFFICIENCY FREE ELECTRON LASER*

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Summary

A high-efficiency free electron laser oscillator experiment is being constructed at Los Alamos National Laboratory. A buncher system has been designed to deliver 30-ps, 5-nC electron bunches to a 20-MeV standing-wave linac at the 60th subharmonic of the 1300-MHz accelerator frequency. The first 108.3-MHz buncher cavity accepts a 5-ns, 5-A peak current pulse from a triode gun. Following a 120-cm drift space, a second 108.3-MHz cavity is used, primarily to enhance the bunching of the trailing half of the bunch. A 1300-MHz cavity with 20-cm drift spaces at each end completes the beamline components. The bunching process continues into the linac's first three accelerating cells. Two thin iron-shielded lenses and seven large-diameter solenoids provide axial magnetic fields for radial focusing.

Introduction

The experimental conditions of the free electron laser oscillator experiment at Los Alamos require a single optical bunch in the 7-m-long resonator. Therefore, the repetition rate of the electron beam bunches must be ∿20 MHz. A pulse train up to 100 μs long is provided to allow time for an oscillation to grow from noise to saturation. The electron bunches in the wiggler must be ∿30 ps long and contain at least 3 nC of charge. Accordingly, the injector is designed to deliver 5 nC per bunch to the linac.

A Litton triode gun with a grid pulser and a postaccelerator was designed to deliver a peak current of over 5 A at 80 keV, with a base width of 5 ns. The computed normalized transverse emittance[1] is ∿25π mm•mrad. Tapered OFHC copper apertures are provided to spatially filter the gun emittance, if necessary, to achieve the required emittance of 1π mm•mrad at 20 MeV in the wiggler.

Choice of Subharmonic Frequency

The length ℓ of the optical cavity is constrained for various reasons to lie between 4 and 8 m and is related to the gun-pulse frequency f_{gun} by $\ell = 150\ f_{gun}^{-1}$, where ℓ is in meters and f is in megahertz. The gun-pulse width must be shorter than a half-period of the first subharmonic buncher-cavity field; therefore, $f_{shb}^{-1} \geq 2$ times the gun-pulse width. Finally, the gun-pulse frequency and the subharmonic buncher frequency must be harmonically related to the linac frequency, 1300 MHz, and to each other. Hence, $f_{shb} = 1300/n$, $f_{gun} = 1300/m$, and $m/n = k$, where k, m, and n are integers. A lower limit on f_{shb} is imposed to minimize the size of the buncher cavities, which are located within the central boreholes of several solenoid magnets.

The chosen parameters are n = 12, m = 60, and ℓ = 6.92 m. For n < 12, the rf period is too short; for n < 13, the cavities are too large; and for m > 60, the optical cavity is too large. Therefore, f_{gun} = 21.67 MHz and f_{shb} = 108.33 MHz.

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Design Calculations

A one-dimensional ring code[2] was used as a guide in selecting the number and location of the buncher cavities and to select field amplitudes and phases in the cavities. This code is the most recent in a long line of computer simulations derived from the large-signal theory of traveling-wave tube amplifiers.[3] The ring radius is assumed to remain constant, while the current's effective value increases as the bunching proceeds.

As a complementary approach, integration of the Pierce paraxial envelope equation[4] was used to determine the axial magnetic field required to maintain Brillouin flow or constant equilibrium beam radius.[5] The axial magnetic field produced by a trial set of collinear solenoids was calculated for use in the paraxial envelope code. The beam current's effective value was assumed to increase linearly from 5 A at the first buncher to 100 A at the end of the bunching region.

The chosen design, based on the foregoing calculations, consists of two subharmonic-frequency buncher cavities and one buncher cavity at the linac frequency. The ring-model calculation shows clearly that under the given input conditions, the initial bunching must be gentle, with a long drift space. A second subharmonic buncher cavity is required to correct a nonlinear bunching that is an unavoidable relativistic effect. Equal and opposite energy changes imposed in the two halves of the sinusoidal buncher field result in different values of $|\Delta\beta/\beta|$, hence different bunching. The second buncher is phased to enhance the bunching of the trailing half of the bunch. Finally, the third cavity is required to compress the bunch sufficiently so as to minimize the energy spread in the high field gradients of the first three accelerator cells, where further bunching occurs.

The bunching voltages, phases, frequencies, and drift distances following each buncher gap are given in Table I.

The charge and energy distributions after passing through the third graded-β linac cell are shown in Fig. 1. The total charge injected into the first subharmonic buncher was 20 nC. In Fig. 1, the total charge in the central peak, 34 ps wide, is 13 nC. In the energy spectrum, the peak, which is 160 keV wide, contains 9 nC.

The results of integrating the paraxial envelope equation with the chosen solenoid parameters are shown in Fig. 2. Brillouin flow was not achieved with the assumed conditions, but the scalloping is small enough to allow the beam to be transported within the available apertures.

TABLE I

BUNCHER VOLTAGES, PHASES, FREQUENCIES, AND DRIFT DISTANCES

Cavity No.	Frequency (MHz)	Peak Voltage (kV)	Phase (degrees with respect to reference ring)	Drift (cm)
1	108.33	30	0	120
2	108.33	18	-30	20
3	1300	20	-10	20

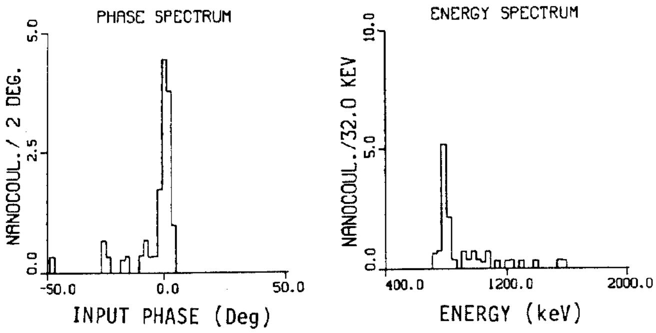

Fig. 1. Linac input phase and energy distributions from the ring-model calculation.

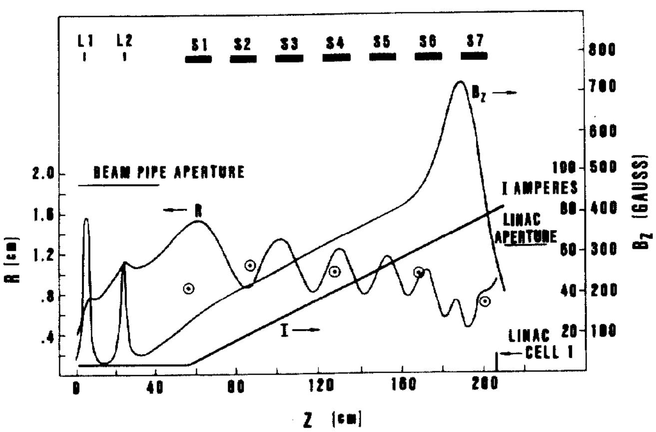

Fig. 2. Beam radius, R, from the integration of the Pierce paraxial envelope equation. The axial magnetic field, B_z, is produced by the set of lenses and solenoids indicated at the top of the figure. The current, I, is assumed. The circles are equilibrium radii from Ref. 5. Buncher beam pipe and linac apertures are indicated.

Buncher Cavity Design

The three buncher cavities are of the coaxial resonator type. In the 108.33-MHz cavities, the overall dimensions were reduced by placing disks on the ends of the inner members of the coaxial structure to provide capacitive loading. Details of the design were established with the aid of the SUPERFISH code. The measured Qs were 7900 and 8400 for the 108.33- and 1300-MHz cavities, respectively.

The cavities are provided with tuning plungers mounted on micrometer actuators with bellows vacuum seals. The tuning ranges available are 0.7 and 0.6% for the 108.33- and 1300-MHz cavities, respectively. Each buncher cavity is provided with a water-cooling coil to stabilize the temperature.

The Injector Assembly

An elevation view of the complete injector assembly is shown in Fig. 3. The beam from the electron gun first passes through two thin lenses of the electromagnet type. Steering coils and a pumping channel are located between the thin lenses.

As the beam approaches the first subharmonic buncher cavity, it enters a tapered axial magnetic field (Fig. 2). The gun itself is shielded from the extremity of this field by a sheet of mild steel placed adjacent to the buncher cavity.

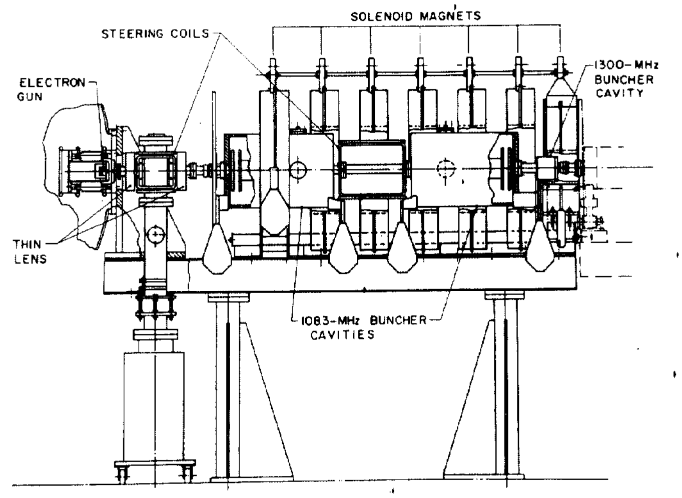

Fig. 3. The injector assembly for the Los Alamos free electron laser oscillator experiment.

A second set of steering coils, a valve, and a retractable fluorescent screen are located between the two subharmonic-frequency cavities. Located before and after the set of buncher cavities are two broad-band wall-current monitors of the type used in the injector for the proposed SLAC Linear Collider.

A graded set of three beam-limiting apertures is provided in the space between the two thin lenses. The apertures are tapered with a 10° half-angle in a 5-cm-thick block of OFHC copper. Tapered apertures located near dispenser cathodes have been shown[6] to eliminate poisoning of the cathodes caused by metal atoms sputtered upon impact of negative oxygen ions emitted from the cathode.[7] The aperture diameters are 4, 6, and 8 mm; a fourth position of the aperture frame presents no obstruction to the beam.

Status

All components of the injector for the Los Alamos free electron laser oscillator experiment have been received and are being installed. The magnetic axes of the large solenoids are being located with a transverse Hall probe. As each buncher cavity and its associated solenoids are installed, bunch width measurements are made with a wall-current monitor and a wide-band current transformer. Emittance measurements are made with a pepper-pot device. Beamlets formed by a tantalum plate drilled with a pattern of 0.13-mm-diam holes are observed on a fluorescent screen after drifting up to 30 cm.

Acknowledgment

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